Modal Mapping Techniques for Geoacoustic Inversion and Source Localization in Laterally Varying, Shallow-Water Environments

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Grant Number: N00014-04-1-0296

LONG-TERM GOALS

The long-term goal of this research is to increase our understanding of shallow water acoustic propagation and its relationship to the three-dimensionally varying geoacoustic properties of the seabed.

OBJECTIVES

The scientific objectives of this research are:

(1) to develop high-resolution methods for characterizing the spatial and temporal behavior of the normal mode field in shallow water;

(2) to use this characterization as input data to inversion techniques for inferring the acoustic properties of the shallow-water waveguide; and

(3) to use this characterization to improve our ability to localize and track sources.

APPROACH

An experimental technique is being developed for mapping the normal mode field and its wavenumber spectrum as a function of position in a complex, shallow-water waveguide environment whose acoustic properties vary in three spatial dimensions. By describing the spatially varying spectral content of the modal field, the method provides a direct measure of the propagation characteristics of the waveguide. The resulting modal maps can also be used as input data to inverse techniques for obtaining the laterally varying, acoustic properties of the waveguide. The experimental configuration consists of a moored, drifting, or towed source radiating one or more pure tones to a field of freely drifting buoys, each containing a hydrophone, GPS navigation, and radio telemetry, as shown in Fig. 1. A key component of this method is the establishment of a local differential GPS system between the ship and each buoy, thereby enabling the determination of the positions of the buoys relative to the ship with submeter accuracy. In this manner, the drifting buoys create 2-D synthetic aperture horizontal arrays along which the modal evolution of the waveguide can be observed in the spatial domain, or after beam forming, in the horizontal wavenumber domain. In this context, two-dimensional modal maps in

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2005**	2. REPORT TYPE	3. DATES COVERED **00-00-2005 to 00-00-2005**
4. TITLE AND SUBTITLE **Modal Mapping Techniques for Geoacoustic Inversion and Source Localization in Laterally Varying, Shallow-Water Environments**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Florida Atlantic University,Department of Ocean Engineering,SeaTech Campus, 101 North Beach Road,Dania Beach,FL,33004**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
code 1 only

14. ABSTRACT
The long-term goal of this research is to increase our understanding of shallow water acoustic propagation and its relationship to the three-dimensionally varying geoacoustic properties of the seabed

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

range *and* azimuth, as well as three-dimensional bottom inversion in range, depth, *and* azimuth, become achievable goals. In addition, these high-resolution measurements have provided significant new insights into source localization and tracking techniques.

WORK COMPLETED

To date, three successful Modal Mapping Experiments (MOMAX) have been completed. Two of these experiments (MOMAX I and SWAT/MOMAX III) were conducted in the East Coast STRATAFORM/SWARM area off the New Jersey coast and one (LWAD 99-1/MOMAX II) was carried out in the Gulf of Mexico. In these experiments, several drifting MOMAX buoys received signals out to ranges of 20 km from moored, drifting, and towed sources transmitting pure tones in the frequency range 20-475 Hz. In the traditional MOMAX deployment, a source transmits a pure tone (usually several) of precisely known frequency to the MOMAX buoys. The known carrier frequency contribution to the total phase is removed from the measured signal, and the resulting pressure field magnitude and phase versus time data are then merged with the corresponding GPS-derived source-receiver positions versus time. This procedure enables the determination of the pressure magnitude and phase as a function of two-dimensional position. High-resolution beam-forming techniques and inverse methods are then applied to these synthetic aperture data to obtain the modal information and the geoacoustic properties of the seabed. In 2005, planning and preparation were begun for participation in SW06, the ONR-sponsored, multi-institutional, multi-ship, shallow-water experiment to be conducted off the New Jersey coast in the summer of 2006. An extensive suite of physical oceanographic measurements is planned for SW06, and therefore a primary focus of SW06/MOMAX IV will be the study of the effects of water column variability on the modal inversion process.

RESULTS

As an example of the modal mapping process, we present the analysis results for one of the experiments conducted during SWAT/MOMAX III. A 20 Hz pure tone was transmitted by the stationary Japanese TLFS source and received on two drifting MOMAX buoys. Because the acoustic wavelength and water depth were comparable in this case (75 m) and the measured signal magnitude showed virtually no interference pattern, it was hypothesized that only a single mode was propagating in this range-dependent waveguide. In that case, the adiabatic mode field *p(r)* as a function of range *r* is given by:

$$p(r) = A_1 \frac{\exp\left[i\int_0^r k_1(r')dr' \right]}{\sqrt{\int_0^r k_1(r')dr'}} \equiv A\exp(i\Phi)\,, \tag{1}$$

where A_1 is the mode amplitude, $k_1(r')$ is the (single) modal eigenvalue, and A and Φ are the measured signal magnitude and phase, respectively:

$$A = \frac{A_1}{\sqrt{\int_0^r k_1(r')dr'}}\,, \qquad \Phi = \int_0^r k_1(r')dr'\,. \tag{2}$$

In that case, the range evolution of the modal eigenvalue can be computed simply by taking the range derivative of the measured phase in Eq. (2):

$$k_1(r) = \frac{d\Phi}{dr} . \tag{3}$$

The results of performing this operation on the 20 Hz data measured on one of the MOMAX buoys (Larry) are shown in Fig. 2. Also shown in the figure are the results from two other, independent spectral estimation techniques that apply sliding windows to the data. One of the methods is an autoregressive technique, while the other utilizes competing forward/backward Kalman filter pairs. It is clear that the results from all three methods are in excellent agreement, thus supporting the hypothesis of single mode propagation. Inversion techniques for estimating the range-dependent sound speed in the bottom from the range evolution of the 20 Hz eigenvalue are currently being examined, initially in the context of a range-varying Pekeris model.

IMPACT/APPLICATIONS

The experimental configuration consisting of a CW source and freely drifting buoys will provide a simple way to characterize a shallow water area and may be useful in survey operations. In addition, the planar, synthetic receiving array may offer an effective new technique for localizing and tracking sources of unknown, quasi-stable frequency in shallow water.

TRANSITIONS

The synthetic aperture technique and Hankel transform inversion methodology which underlie the modal mapping method have been implemented in the ACT II experiment, sponsored by DARPA and ONR, and will be used in the REMUS towed array experiments being conducted by Carey and Lynch. This approach has also been adopted by several research groups internationally, including the Japanese groups involved in SWAT. In SW06/MOMAX IV, it is our intention to deploy a COTS sonobuoy system in parallel with the MOMAX buoys as part of the transition process to the operational Navy.

RELATED PROJECTS

MOMAX I and III were conducted in the same area off the New Jersey coast where the ONR-sponsored STRATAFORM, SWARM, Geoclutter, and Boundary Characterization experiments were carried out. The extensive geophysical, seismic, acoustic, and oceanographic data obtained in these experiments are being used to ground truth the MOMAX measurements.

The LWAD 99-1 Project included a broad range of underwater acoustic and environmental measurements, in addition to MOMAX II. The results from these other experiments are being used to assist in the interpretation of the MOMAX II data.

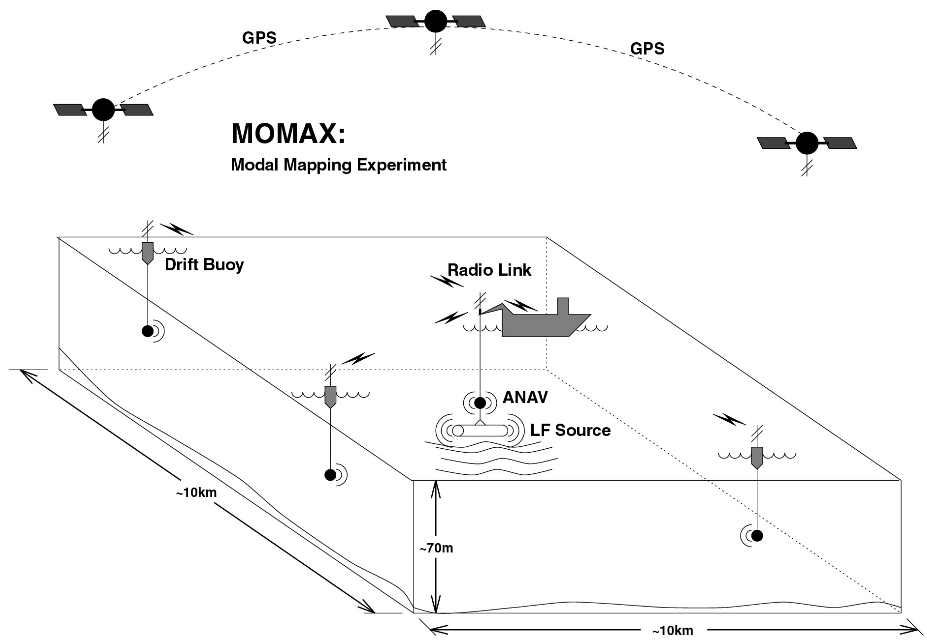

Figure 1: MOMAX experimental configuration.

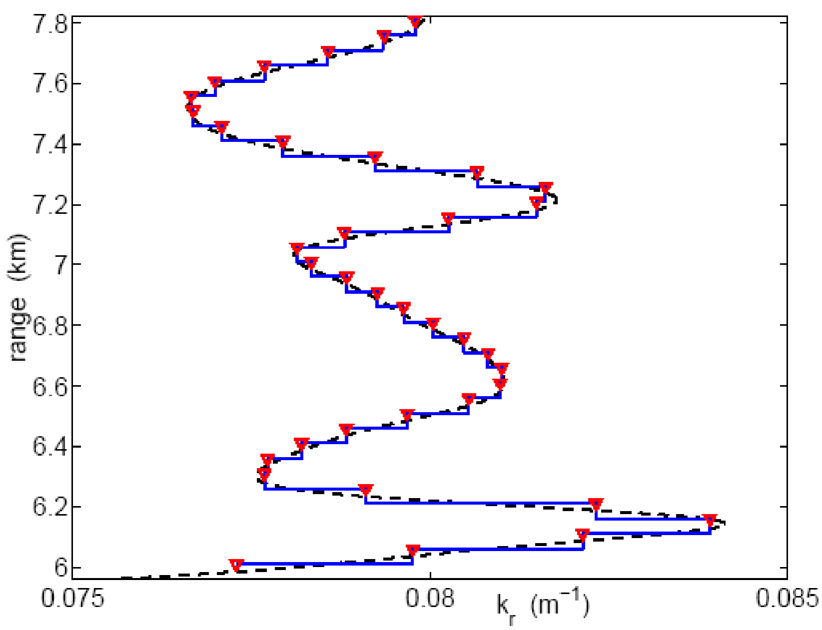

Figure 2: Range evolution of the single modal eigenvalue at 20 Hz obtained using 3 techniques: phase differentiation (dashed line); order 1 autoregressive (AR) spectral estimation (solid line); and 3 competing forward/backward Kalman filter pairs (triangles).

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